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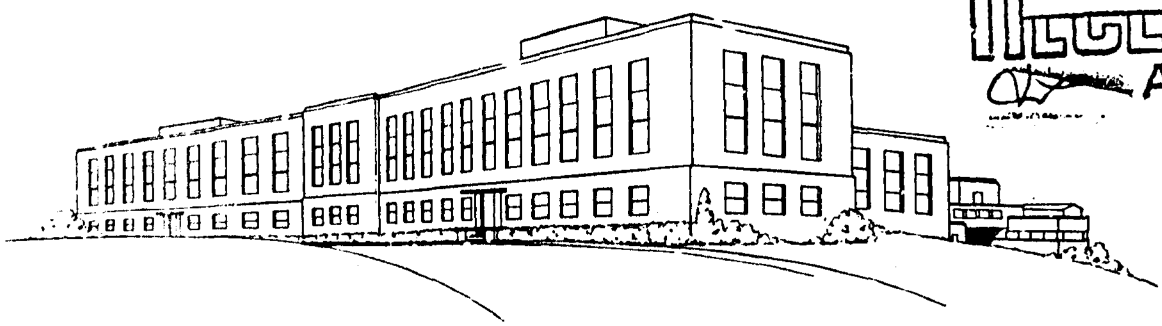



**THE PRINCIPLES OF PROTECTION OF THE HUMAN BODY AS APPLIED IN A RESTRAINING HARNESS FOR AIRCRAFT PILOTS**

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13. ABSTRACT

A restraining harness for aircraft pilots has been develop[illegible] which has successfully protected volunteers against 2500 foot-pounds delivered on th[illegible] impact decelerator by dropping a 500 pound weight five feet. This impact force expended in 0.15 seconds on a dummy enclosed in a semi-rigid harness is featured by 10,000 pound peaks as measured by strain gages.



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# THE PRINCIPLES OF PROTECTION OF THE HUMAN BODY AS APPLIED IN A RESTRAINING HARNESS FOR AIRCRAFT PILOTS*

Research Project X-630 — Report No. 6


## SUMMARY

1. A restraining harness for aircraft pilots has been developed which has successfully protected volunteers against 2500 foot-pounds delivered on the impact decelerator by dropping a 500 pound weight five feet. This impact force expended in 0.15 seconds on a dummy enclosed in a semi-rigid harness is featured by 10,000 pound peaks as measured by strain gages.

2. The factors which contribute to the effectiveness of this harness are;

a. Distribution of the impact load over a large body area.
b. Distribution of the impact load to regions of the body best able to withstand high impact forces.
c. Gradual rate of application of force due to high initial elasticity of the material.
d. Damping of small irregularities during the period of impact.
e. The property of the material to elongate inelastically when the applied force reaches a predetermined tolerable limit, permitting the absorption of large amounts of energy.


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*The opinions or conclusions contained in this report are those of the author(s). They are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department. Reference may be made to this report in the same way as to published articles noting author(s), title, source, date, project number and report number.

## INTRODUCTION

During the past seven months investigations of the effects of impact forces upon the human body have been carried out with the impact decelerator (fig. 1) previously described (1). In an airplane crash the pilot or aircrewman is flung forcibly forward against his restraining harness. The impact decelerator produces stresses on the subject by jerking the harness backward against the abdomen and shoulders, and offers a highly useful and convenient technic for studying impact forces of the order of magnitude of those which are believed to occur in an aircraft crash.

The conventional safety harness transmits impact forces to the subject over a relatively narrow area of body surface (2). The forces transmitted to the body with this harness during an impact are unevenly distributed and are concentrated at the umbilicus and the clavicular areas, suggesting the need for modification. The first modification (model A) employed a vest-type garment with an area of 156 sq. in. and distributed the forces over twice the area of the body covered by the conventional harness (3). This harness, constructed of semi-rigid, drawn, heavy nylon fabric, was capable of offering increased protection against larger impacts.

The limit of tolerance of the human body to impact using the regulation type harness (area about 76 sq. in.) was found to be about 2000 pounds impact produced by dropping 165 pounds from three feet. When a semi-rigid vest-type harness (model A) was used (area about 156 sq. in.) the tolerable limit was increased to 3300 pounds, obtained by dropping 165 pounds from five feet.

The criteria for tolerance of the volunteer subjects used in these experiments were the appearance of cutaneous ecchymoses or the initial suggestion of injury to ligaments, muscle or bone - the type of injury which occurs frequently in football. These clinical findings together with changes in the electrocardiogram, respiratory pattern, together with subjective complaints, and observations of the investigator served to fix the end point of maximal tolerable impact. It was soon found, however, that the impact curve recorded by the strain gages followed a fairly characteristic pattern for any type of semi-rigid harness (fig. 2).

Figure 2 shows a strain gage tracing of a 10,000 pound impact applied to a dummy in a semi-rigid harness. The impact was produced by dropping a 500 pound weight from a height of five feet equivalent to 2500 foot-pounds of energy. The duration of impact is 0.17 seconds, but its maximum force occurs during the first 0.06 seconds. The sharp peak represents the type of impact force which the subjects have found to be least tolerable. A human probably could not survive this impact of 10,000 pounds. Since an effective, protective harness must prevent this

full impact from reaching the subject, this drop of 500 pounds from five feet was used for the final test purposes. A reference to the "maximal load" means this drop involving 2500 foot-pounds which produces a 10,000 pound peak impact on a dummy using a semi-rigid harness.

Since the torso is asymmetric and since various parts of the body are more resistant to impact than others it is essential that provision be made to distribute the forces to the parts most capable of absorbing the energy of the impact. This distribution of impact forces must also be such as to minimize shearing effects on the body caused by uneven forces.

Further investigations with the impact decelerator and high speed cinematography yielded information concerning the effects of the initial part of the impact. The rate of loading was found to bear a relationship to the maximal tolerable load (4). Rapid application of the impact causing the peak to occur in less than 30 or 40 milliseconds was very uncomfortable. In general, the slower rates of loading were preferred (5).

Another series of experiments indicated that subjects undergoing impact prefer the force to be evenly applied. Irregularities of the force proved to be particularly disagreeable.

The potential energy produced by an impact is proportional to its force multiplied by the distance traveled. Large peaks of force can be effectively avoided by slightly increasing the distance of travel. Undrawn nylon elongates in direct proportion to the kinetic energy applied. It has insignificant recoil. This material can be made so that it begins its stretch at loads below the injury threshold.

The lower curve of figure 2 represents a desirable and practical impact force whose characteristics are based on previous data. The curve rises slowly. It has no irregularities, and it stays below the injury producing level. Its plateau is maintained for 0.15 seconds before it drops off to the base line. Its duration is longer, 0.24 seconds as compared to 0.17 seconds, but it represents the same "maximal load". Although its plateau is 3250 pounds it occupies the same area on the graph (contains the same energy) as the shorter impact whose maximum peak is 10,000 pounds.

It was felt that an impact which closely followed such a force-time pattern would be least likely to produce injury. Three harnesses (models A, B, C) were constructed in an attempt to approximate this curve and therefore allow the human body to withstand safely larger impact forces. Model B harness was used in the initial stages of development of the principles for protection against impacts. It was discarded in favor of a later and more finished model.

## EXPERIMENTAL DESIGN

The impact decelerator was used to produce impacts to test the new restraining harness (model C) on volunteers. A "maximal load" was utilized. Measurements of the total force as well as of the pressure exerted by the harness against the anterior chest wall were recorded by small wire strain gages.

The model C harness covers the thorax and abdomen and has an area of 156 sq. in. (fig. 3). The harness is a combination shoulder strap and lap safety belt. It is in the form of a vest which has two straps leading from the shoulders and two straps leading laterally from its abdominal portion. The vest portion of the harness which is in contact with the thorax and abdomen is made of undrawn nylon duck (90" x 61" count by yarn). The strap material is made of undrawn nylon* only in the lengthwise direction. The cross filler thread is drawn nylon and does not stretch significantly during impact. The vest material stretches slightly in both directions upon impact permitting the garment to form-fit the torso and thus distribute the load in proportion to the pressure exerted by the body contacting it. Since undrawn nylon has a lower elastic constant than conventional harness webbing, it will stretch more before the draw load is reached and therefore apply the load more gradually. As soon as the impact load reaches the draw load of the undrawn nylon strap material, which is placed at an impact load known to be safe for the human, the strap will increase in length in an amount related to the force developed. It will continue to elongate without recoil until it reaches a limit beyond which it stretches like drawn nylon (fig. 4).

## RESULTS

Impact forces were gradually increased to a "maximal load" and were easily tolerated by volunteers using the undrawn nylon (model C) harness (fig. 5). The effect of this impact on the subjects while wearing the model C harness was considerably less distressing than in previous tests using a semi-rigid harness with loads one-fifth this magnitude. The subjects also felt that the impact load was applied more gradually and with less shock than if a semi-rigid harness had been used. The volunteers reported that the load during impact was distributed more comfortably over the torso. Specific areas of pressure were not observed beneath the harness. Untoward reactions were not apparent. The subjects stated unanimously that they preferred the "maximal load" with the model C harness to 2000 pound impacts (165 pounds dropped from three feet) with the semi-rigid (model A) harness.

*This material was treated and supplied by All American Aviation, Inc., Wilmington, Delaware. Undrawn nylon as yet remains in the experimental stage.

Physiological data recorded during and after varying impacts with different harnesses are to be presented in a separate report (6). These data closely parallel the subjective reactions of the volunteers. With the model C harness no physiological changes occurred comparable to those seen following impacts delivered when the semi-rigid harness was worn.

With the factors presented in the summary of this report, incorporated in one harness (fig. 6), it has been possible to protect an individual against 500 pounds dropped three feet with but six inches of decelerative distance. The material in the model C harness begins to stretch at a draw load of 2200 pounds. With "maximal loads" the model C harness stretches 13 inches. Using undrawn nylon that begins to elongate at higher draw loads the harness stretch for the "maximal load" will be less.

## DISCUSSION

The effectiveness and adaptability of a vest-harness device for the protection of personnel in aircraft against linear acceleration depends upon the character of the force encountered and many other factors that can be unequivocally evaluated only by experimental aircraft crashes. What has been outlined are the underlying principles employed to secure maximal protection against the type of force produced by the impact decelerator, and the demonstration of the comparative value of different types of harness to achieve this type of protection.

The conventional harness protects effectively against impacts of 2000 pounds on the impact decelerator. Subjects using a harness of larger area over the thorax and abdomen have tolerated impacts of 3300 pounds. When such a harness incorporates the features of maximal area and more equal distribution to the torso, the human can tolerate greater impact loads. If the rate of loading is slowed and irregularities in the force applied are removed, the injury threshold is still further raised. And if, in addition to the above factors, a small distance of controlled stretch without recoil is employed, a "maximal load" can be effectively absorbed without injury.

It is known from previous studies (3) that an individual wearing a semi-rigid harness can successfully withstand impact loads only as high as 3300 pounds without tissue damage. Attempts to exceed this force have led to injuries.

The basic protective principle in the model C harness is the stretching of the undrawn nylon without recoil under a draw load below the injury threshold for body tissues. The excess energy which would otherwise cause tissue damage is absorbed by the harness without

injury to the wearer. It is this type of protective deceleration involving either the stretching of material or the absorption by material compressed through distances of the order of six inches that no doubt enabled individuals as reported by DeHaven (7) to survive falls estimated to exceed 200 "g's".

It follows then that the draw load for a protective harness for use in aircraft should be set at a reasonable level below that of the injury limit. This is the critical consideration. Higher draw loads will decrease the amount of decelerative distance but at the expense of probable tissue damage.

Drawn nylon appropriately treated can be manufactured to meet specifications which fit the particular situation. Any material with similar properties should be equally effective.

The available seat-to-gun sight distance varies for all aircraft (8) and is the critical factor toward limiting the maximal protection one can afford such personnel utilizing the principle of added deceleration.

In a fatal airplane crash whose duration approaches one second, it is believed that impacts of lethal magnitude are produced during only a brief portion of the total time (fig. 7). It is felt that adequate protection against these accelerative peaks is the first essential in the saving of lives otherwise lost through crash injuries.

In an aircraft crash the forces are applied first to the aircraft structure and then transmitted to the pilot through the structures leading back to the seat and its attachments to the restraining devices. During such transmission of force, there is undoubtedly an absorption of energy so that the force reaching the subject is less than the initial force at the point of the impact of the aircraft (9). The amount of energy that can be absorbed by the aircraft structure during a crash is unknown. Whatever this absorbed energy, which may be termed "factor x", it acts to protect the individual. Hence, if the model C harness protects the individual against 40 "g's", it should then suffice to protect the individual against impact forces developed in aircraft that crash with forces exceeding 40 "g's" by the unknown structural absorption factor x. Therefore, it is apparent that the cockpit must be made sufficiently strong to resist forces of at least this magnitude.

The principles outlined in this report may be applied to protection against many other types of large accelerative forces that may be encountered, for example, in automobile and train accidents.


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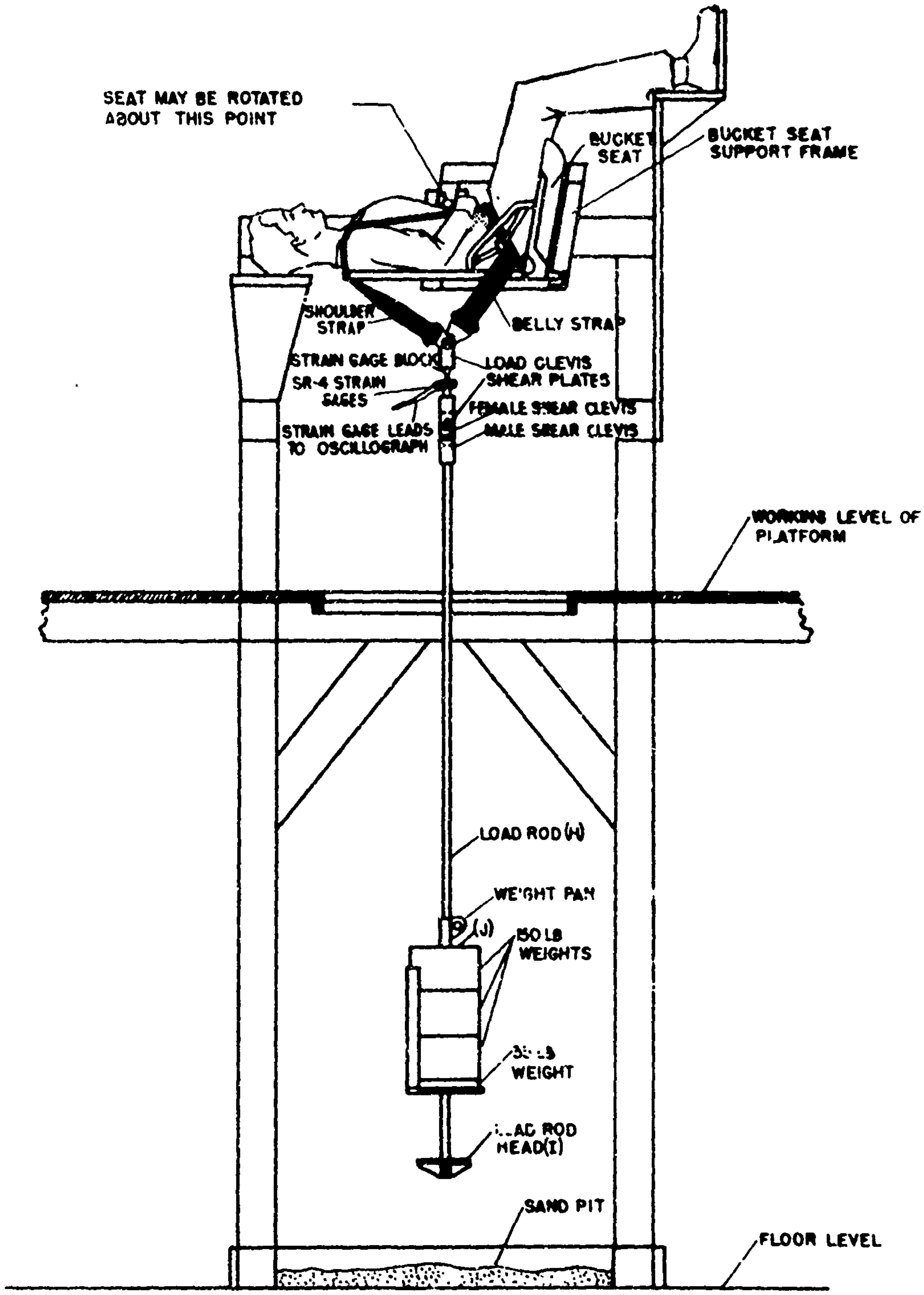


**The Impact Decelerator**

Figure 1.— Impact forces are transmitted to the subject through the rod (H) and shoulder and belly straps by the arresting of falling weights (J) by the load rod head (I). These forces are measured by SR4 wire strain gages attached to the rod.

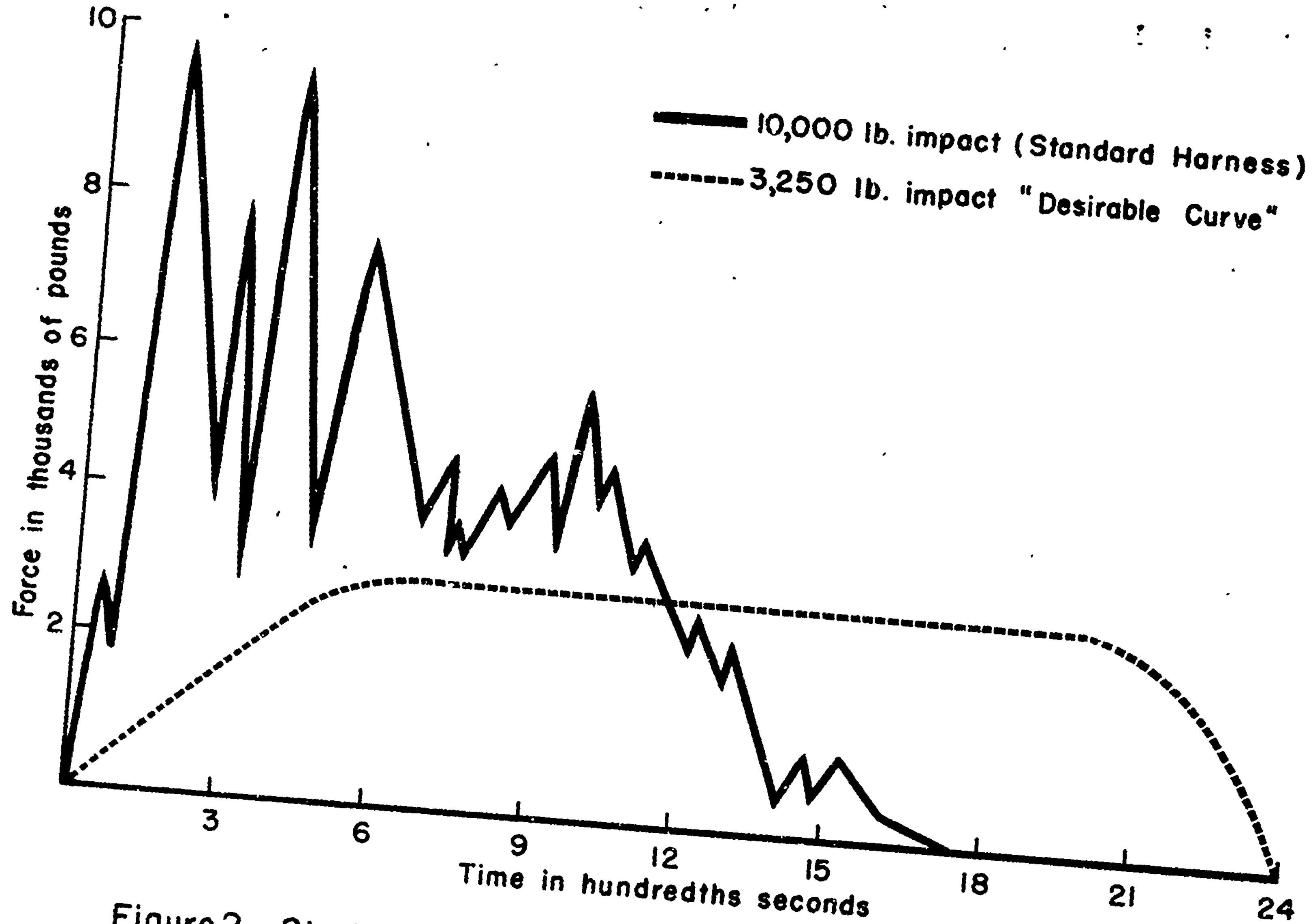


Figure 2.- Strain gauge tracing of an actual 10,000 lb. impact on a dummy, contrasted with "Desirable" impact force curve.



Figure 3.—Subject wearing model "C" harness on the impact decelerator. Measuring devices (ear photo cell and respirometer) are also shown

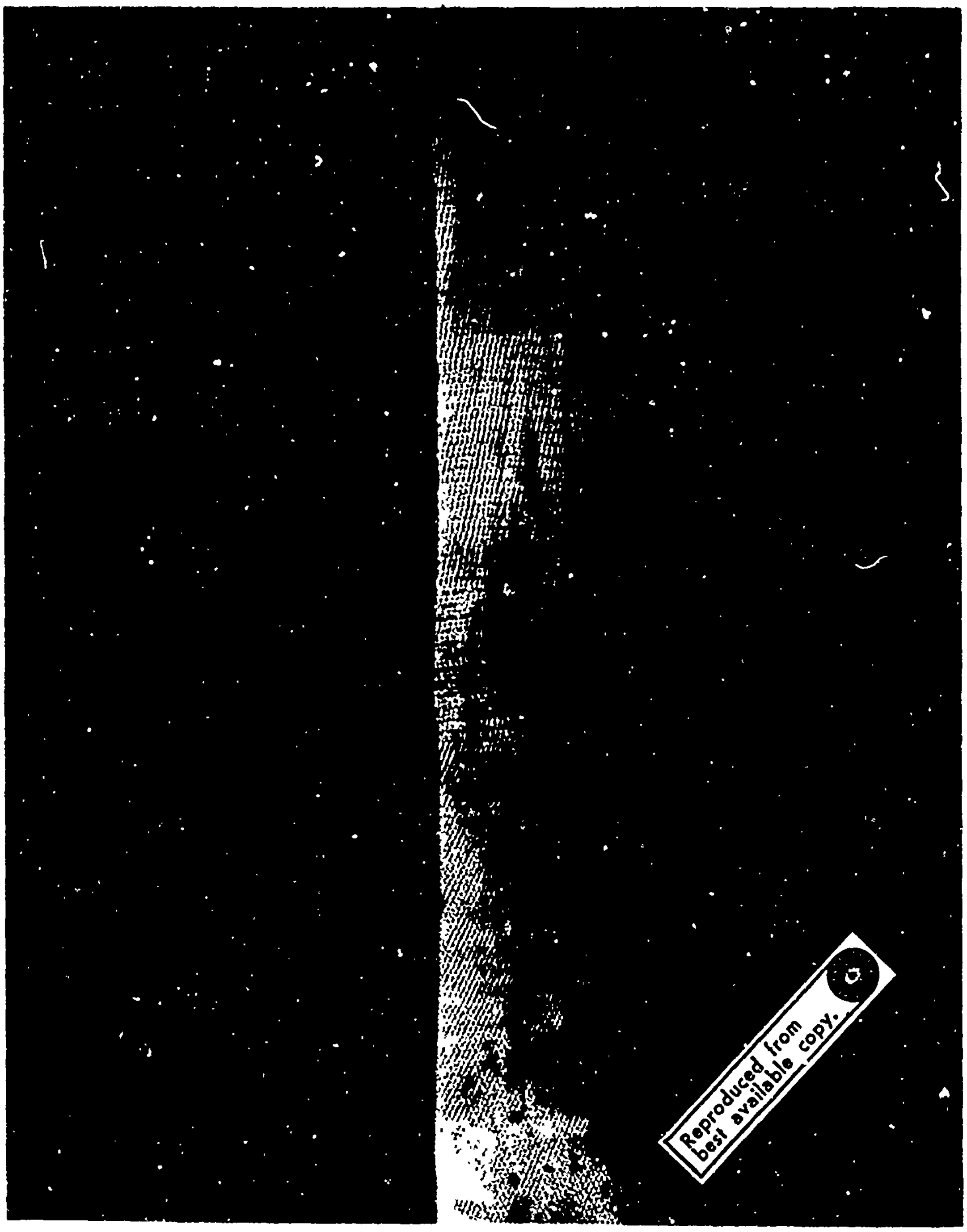


FIGURE 4.—Close-up of shoulder strap. Note the difference in distance between the ink marks in the stretched and unstretched portions of the strap. Prior to impact these marks were equidistant

Figure 5.- Strain gage recording on subject H. W. H., wearing model "C" harness, of a "maximal impact" produced when 500 lb. were dropped from five feet on the impact decelerator. The upper curve represents the pressure record produced by the vest pressing against the anterior chest wall. 1.34 centimeters of deflection of the curve are equivalent to 7.06 psi. The lower recording is a total force curve as measured by the block gage. 2.08 centimeters of deflection represent 2209 lb. impact force. Timing lines are 1/60 of a second. It can be seen that at no time does the subject receive more than 2209 lb. impact despite the fact that this same load would produce 10,000 lb. on a dummy had a semi-rigid harness been used.

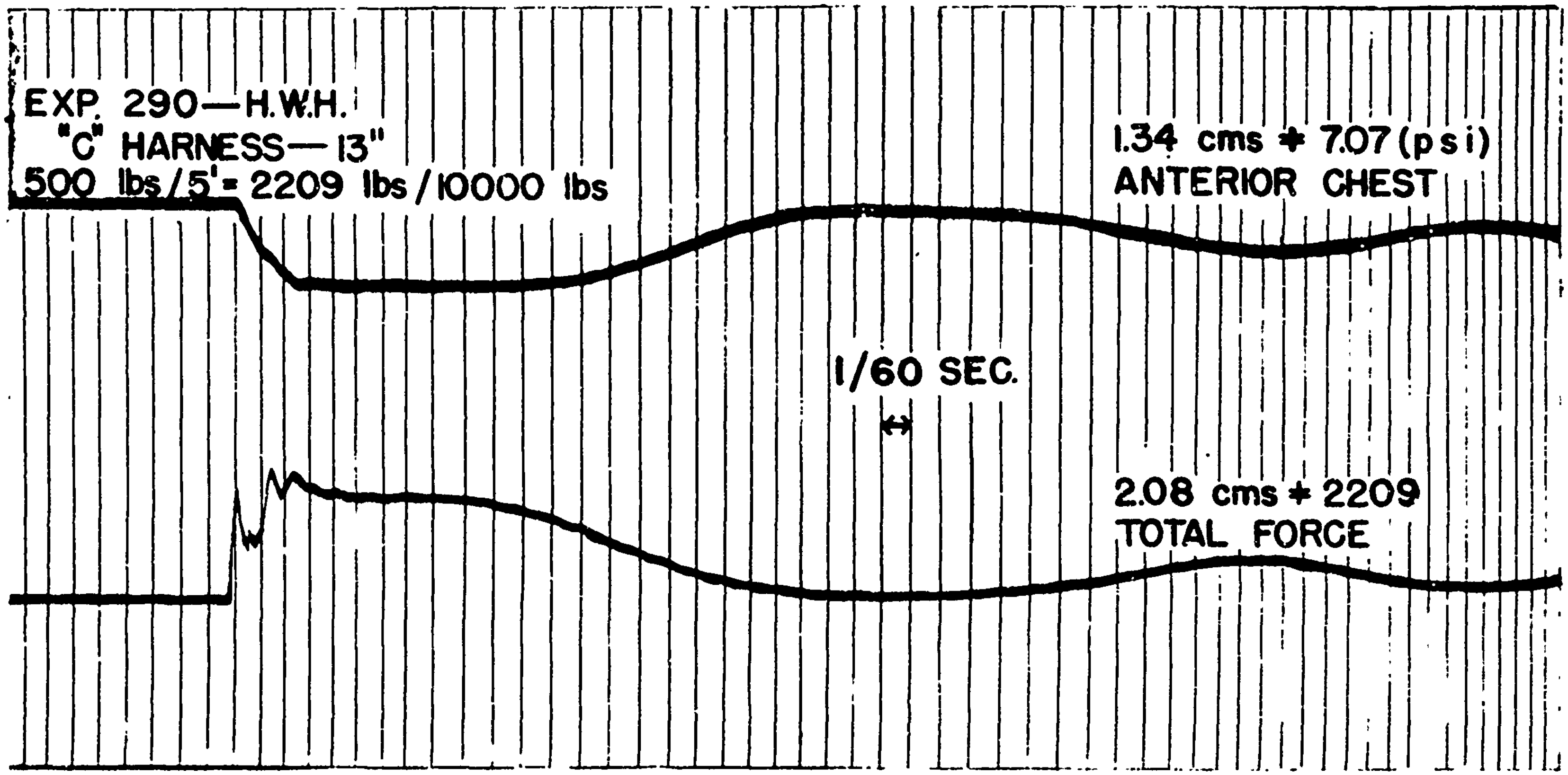


Figure 5.—Strain gage recording of "Maximal Impact"

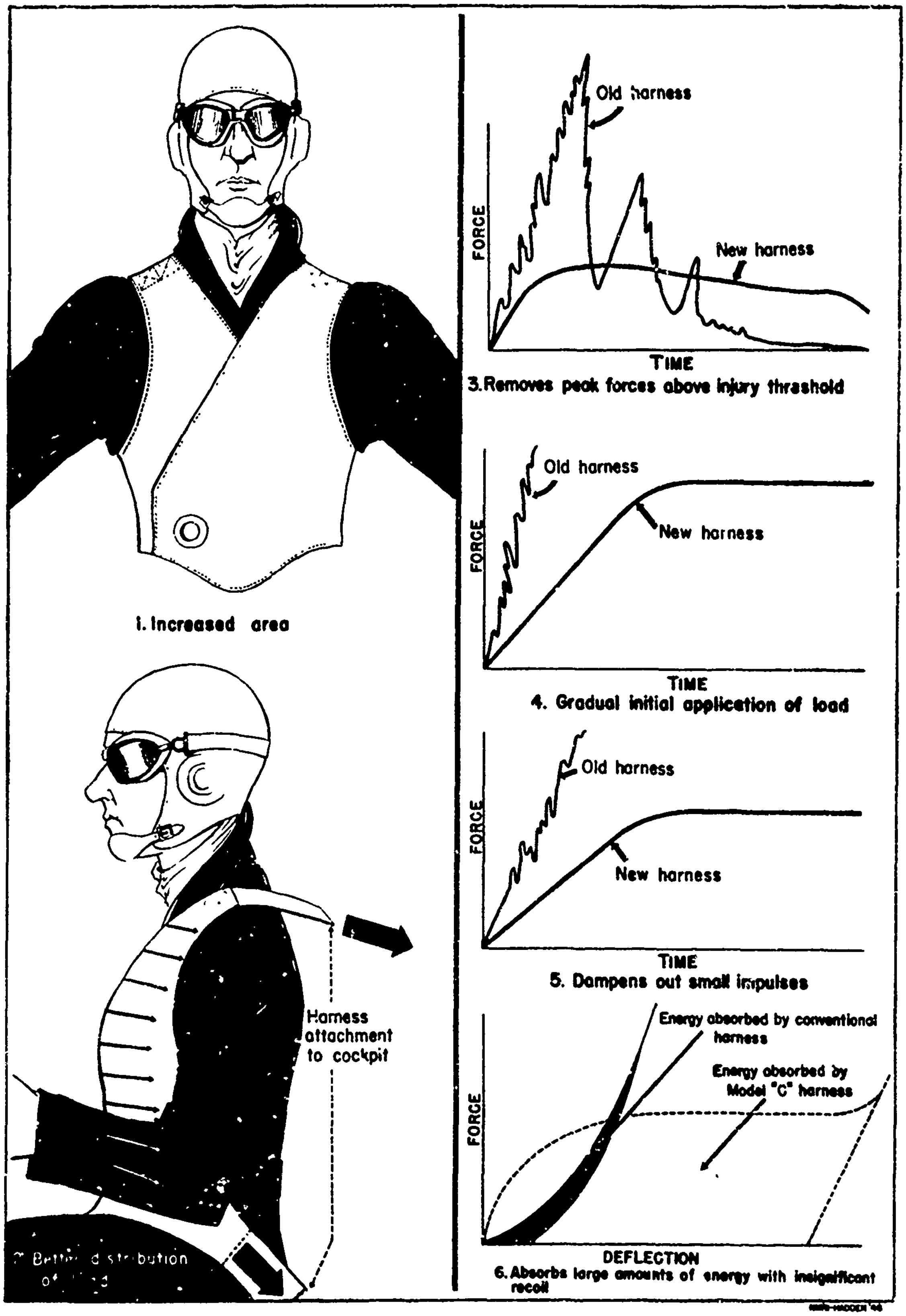


Figure 6.—Diagram to illustrate features of protection embodied in new (Model C) harness. The schematic time-force curves apply to forces as produced with the impact decelerator

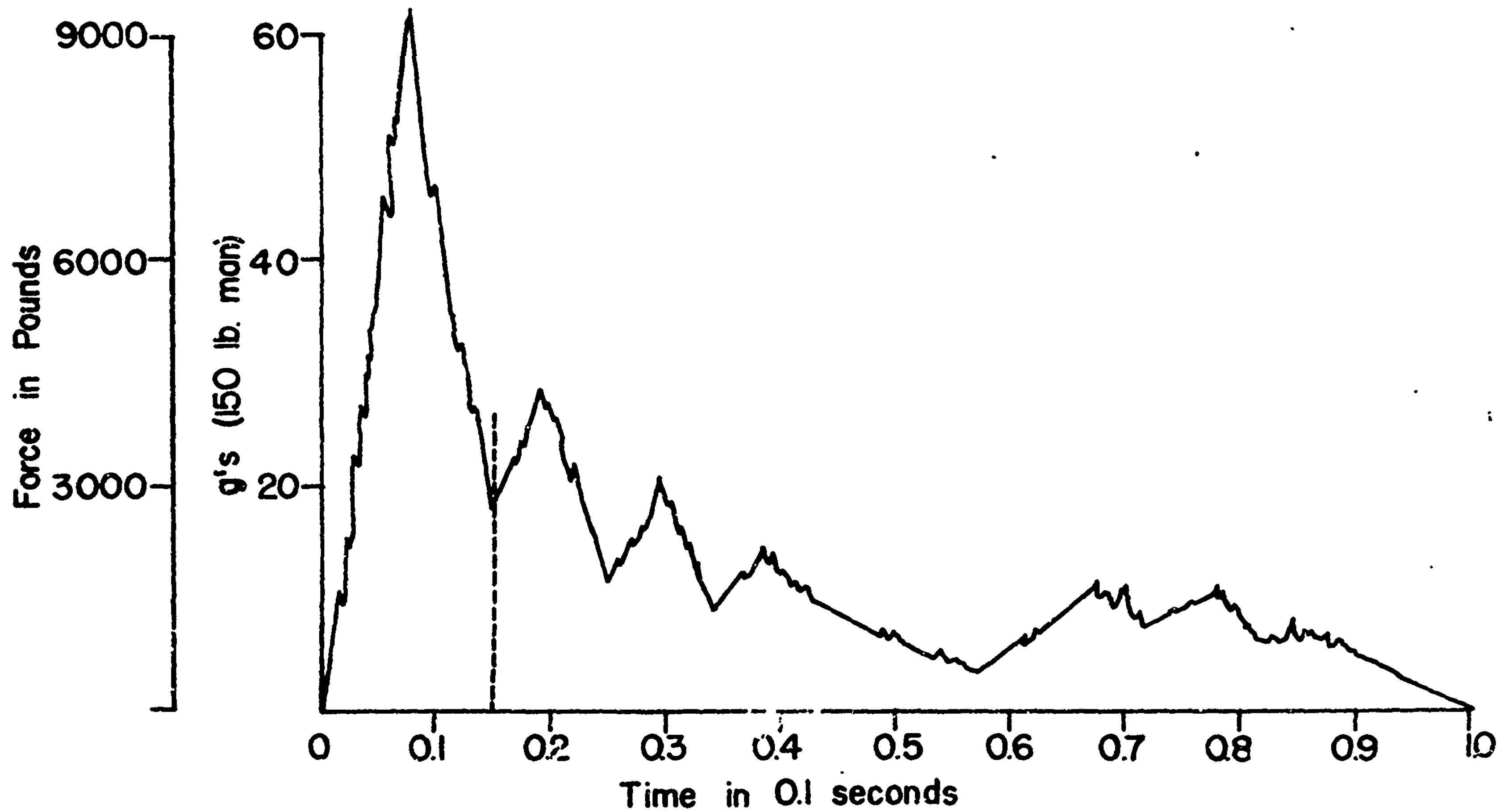


Figure 7.—Hypothetical illust·ation of the impact forces occurring during an aircraft crash of 1 second total duration. The injury threshold is exceeded only during the first 0.15 seconds